

UHF Relay Antenna Measurements On Phoenix Mars Lander Mockup

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ABSTRACT

The Phoenix Lander, a NASA Discovery mission which lands on Mars in the spring of 2008, will rely entirely on UHF relay links between it and Mars orbiting assets, (Odyssey and Mars Reconnaissance Orbiter (MRO)), to communicate with the Earth. As with the Mars Exploration Rover (MER) relay system, non directional antennas will be used to provide roughly hemispherical coverage of the Martian sky. Phoenix lander deck object pattern interference and obscuration are significant, and needed to be quantified to answer system level design and operations questions. This paper describes the measurement campaign carried out at the SPAWAR (Space and Naval Warfare Research) Systems Center San Diego (SSC-SD) hemispherical antenna range, using a Phoenix deck mockup and engineering model antennas. One goal of the measurements was to evaluate two analysis tools, the time domain CST, and the moment method WIPL-D software packages. These would subsequently be used to provide pattern analysis for configurations that would be difficult and expensive to model and test on Earth.

Keywords: Mars Antennas, Range Evaluation, Relay, Scattering, Spacecraft Antenna Measurements

1.0 Introduction

This paper discusses the measurement campaign to characterize the radiation patterns of the UHF relay antennas mounted on the deck of the Mars Phoenix lander, scheduled for launch in the summer of 2007. An important goal of the measurements was to evaluate and validate the use of two different analysis packages, which would be used to help fully characterize the relay performance of the lander in its final configuration.

The Mars Phoenix lander [1] will land at high Mars latitude (near 67.5°) in the spring of 2008. During its 90 sol prime mission Phoenix will, among other scientific investigations, probe the surface for ice, in keeping with NASA's Mars exploration theme of "follow the water".

The surface phase of the mission will rely entirely on relay links with Mars orbiters (Odyssey, MRO) to communicate with earth. There will be no direct communications to or from earth.

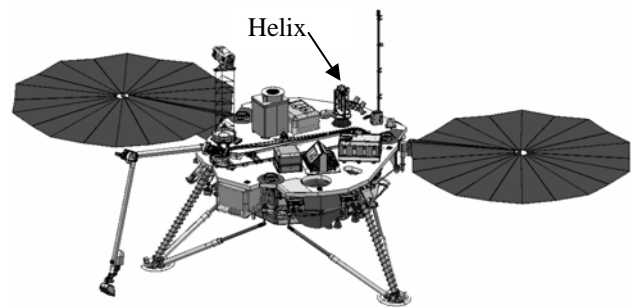


Figure 1 Phoenix Lander Deployed on Mars surface

This telecom plan is somewhat unique for a NASA mission and the operational constraints and consequences are discussed by Lewicki et. al. [2]. Previous lander missions (Viking, MER) have used relay but not exclusively, and as such a characterization of the Phoenix relay antenna performance was crucial. The proposed relay antenna used a helix positioned on the deck, surrounded by deck instruments. With a wavelength of about 29 inches, several deck objects lie well within a wavelength distance, and the helix pattern was expected to be greatly distorted. The extent of the distortion had to be quantified to validate the operations communications strategy, investigate the necessity for a second (redundant) antenna, and to provide measurement data for comparison to pattern predictions which could be used to investigate the patterns after the deck configuration was finalized.

One of the problems for MER operations continues to be the inadequate ability to predict pass data volume performance, primarily due to the uncertainties in the UHF antenna patterns for both the orbiter and the landers. Validating new pattern analysis tools will allow the generation of better prediction models for Phoenix and future missions such as Mars Science Laboratory (MSL).

2.0 Phoenix Lander & SSC-SD Range Qualification

The chosen position for the helix antenna, shown in Figure 2, was expected to cause significant pattern distortion. Initial operations assumptions, which included a 20° elevation mask for link calculations, had to be validated with realistic patterns. Phoenix has a requirement to land with the digging arm side pointing north to within $\pm 5^\circ$. It was evident that due to deck objects the helix pattern would be obscured in the north north-west direction at low elevation angles. The operations plan included commanding the lander in the Martian mornings [2], using low elevation orbiter passes which are predominantly to the north-west, near 7am local solar time. For this, and also for redundancy reasons, it was suggested that a second MER type monopole antenna be positioned on the north-west corner of the deck, as shown in Figure 2.

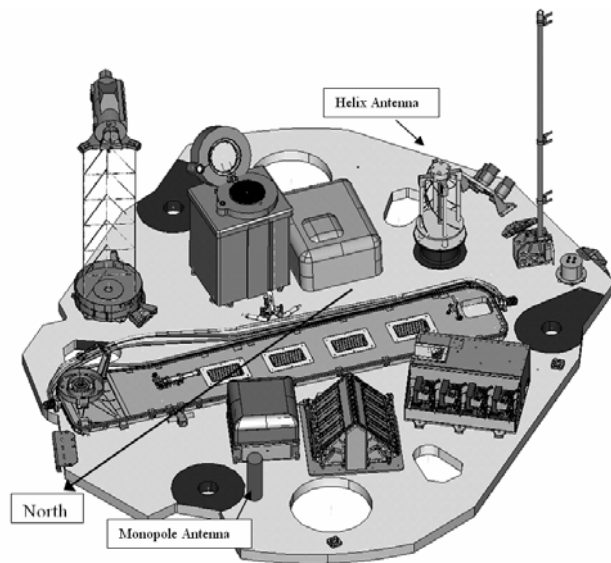


Figure 2 Phoenix Deck Antennas and Deck Objects

Measurements and predictions would be necessary to investigate the performance of such an antenna, especially due to the close proximity to deck instruments.

The lander transmits telemetry and data at a frequency of 401.58 MHz, and receives commands at 437.1 MHz. The operating polarization of orbiter assets and lander helices is RHCP. The monopole, of course, is linearly polarized, as is the MER UHF relay antenna. Being a NASA Discovery mission dictated that budget and schedule were tight. A partial mockup structure was available from a previous incarnation of the mission, the cancelled 2001 lander, and could be upgraded to serve as a Phoenix mockup for antenna measurements. After some investigation, it was decided to perform the pattern measurements at the arch antenna range at the Space and Naval Warfare Systems Center facility in San Diego,

SSC-SD. The range, shown in Figure 3, is primarily used to simulate and measure antenna patterns of naval vessels on a flat ocean, using scaled models. An advantage of using the SSC-SD range was that the Phoenix mockup would sit on the ground, which eliminated building a mechanical structure to mount the mockup on a moving tower, minimizing expense on mockup construction, as well as schedule savings. Furthermore ground effects on the radiation patterns could be studied. A major disadvantage was the fact that these ground effects of the range surface were hard to eliminate if so desired. Also, during the range evaluation using a SSC-SD supplied monopole, mounted on the range surface ground plane, a range ripple was identified. The ripple, predominant at low AUT signal levels. Though its cause was not explained, it could be produced by a constant leakage signal, about -25 dB down from the peak of the monopole antenna signal, beating in and out of phase with the AUT signal. Since it was significant only at low signal regions, such as near nulls, it was decided to accept the error. For pattern gains above -5 dB the ripple was $< \pm 1$ dB.



Figure 3 SSC-SD Arc Antenna Range

A small quantity of microwave absorber (18 pieces) was available to help lessen ground scattering for some scan studies, though there was never enough to completely remove ground scattering effects on the patterns. Another disadvantage of the range is that the range probe track provides only a single 90° elevation scan. This precludes the ability to perform plunge cuts, cuts that repeat on opposite sides of the range, often used to evaluate range contributions to pattern measurement uncertainties.

The measurement probe antenna, a log-periodic dipole supplied by SSC-SD, is mounted on a moving platform running up the left most arch in Figure 3, which is rotated 90° for CP reconstruction from two linear polarization measurements. The AUT sits on a 22' diameter rotating platform at the center of the spherical arch. The arches are

constructed from a fiberglass material, minimizing R/F scattering. The radial distance from the sphere center to the probe was $\sim 75'$. Since JPL had not used the SSC-SD facility before, an alignment study of the arch system and probe platform was performed to establish position repeatability. Laser range finding data demonstrated that the error in space loss due to arch radius variations was < 0.1 dB, while the angular error at any given probe position due to side to side and arch length variation was $< 0.25^\circ$. These errors were small compared to what was expected from ground scattering and other sources, and well within what was required. A set of stability measurements were also made at zenith and 45° elevation, to check for temperature and wind effects, and it was found that the range maximum movement was < 0.4 inches. Equipment stability and repeatability was studied by shorting the probe end of the range cable, and recording S11. The amplitude variations along the full 90° arch motion was found to be < 0.1 dB, while phase variation was $\sim 10^\circ$. The standard rule of thumb for calculating the far field distance for pattern measurements, $[(2 * D^2) / \lambda]$, yields an aperture size of about 9.5 ft. for the SSC-SD range. Technically the Phoenix deck meets this criteria. Including the solar panel exceeds this size, however their effects on the pattern are secondary, and the rule violation was deemed acceptable.

A standard spherical coordinate system was used for data recording, with $\theta = 0^\circ$ being in the range zenith direction (range elevation = 90°), and ϕ being in the range azimuth direction. A standard set of θ positions were used throughout the measurement campaign, from 87° (the lowest possible probe position) to 30° in 3° steps, then 30° to 0° in 5° deg steps (since there were a denser grid of points near zenith). In azimuth, data was measured every 1° .

An important difference between this measurement campaign, and traditional antenna measurements, is that relay, as has been implemented for Mars missions, is inherently a statistical process. The landers and orbiters at Mars use the CCSDS Proximity-1 [3] protocol, which protects against link breakage, by keeping track of the frames of data that have been received successfully, and requesting retransmission of missed or distorted frames. This permits the use of non-directive antennas on landers and orbiters, which is a considerable savings with respect to spacecraft mass, cost, and operations. Unfortunately, low directivity antennas will suffer the most from deck scattering and obscuration. Since the protocol takes care of low signal levels and drop outs due to pattern distortions, the required accuracy of the knowledge of the antenna patterns is less than for traditional link calculations. Nevertheless the patterns must be investigated to insure there are no major (unexpected)

pattern problems, and that the antenna terminal impedances are not overly degraded due to the proximity of deck objects. In these terms, the tests at SSC-SD were more of a systems engineering study, than a traditional antenna measurement campaign. The goal was to get enough information, with a small budget, to be able to make system engineering decisions, as well as to obtain data for comparison against predictions.

3.0 SGH and Scattering Study Results

After performing range evaluation tests, a standard gain horn (SGH) was used to provide a gain reference. To investigate range ripple (which would include error signals as discussed previously and range scattering) a test was performed with the SGH pointed to zenith, and an S21 frequency sweep was performed around the frequencies of interest. This is somewhat equivalent to performing a series of $\frac{1}{4} \lambda$ tests. The ripple was found to be about 1 dB peak to peak.



Figure 4 SGH Reference Measurement Configuration

This puts a lower bound on the measured gain accuracy expected. It was found that pattern ripple was somewhat angle dependant, and after some experimentation it was decided that the SGH reference should be taken at about 45° elevation, as shown in Figure 4, where the peak to peak ripple was found to be < 1 dB. Ground effects were expected to be significant, which was useful for evaluating the worst case pattern effects on Mars, but were also inconvenient when trying to get a more realistic picture of what the patterns would look like in situ. Since the surface of Mars is neither flat and smooth, nor highly conductive, as is the SSC-SD range surface, the worst case ground scattering would be a far too conservative evaluation case. Figure 6 models the expected worst case SSC-SD range specular scattering. The radiating antennas would be about 1 meter above the ground, and indeed the expected scattered signal calculations agreed well with measured data. The model shows that the most important

specular scattering occurs within about the first 4 meters from the AUT. This was significant since with a small amount of absorber available we could mitigate only a limited amount of scattering. It was found that careful placement of absorber near the AUT could significantly attenuate the scattering when desired. To verify the expected scattering, and optimize the use of our limited absorber stock, the pattern of a drooping ground plane monopole, mounted on a pedestal about 1 meter high, was measured. Figure 7 shows the absorber pattern placed close to the monopole. Figure 8 shows measured cut data with the close in absorber, absorber laid farther away from the AUT, and no absorber. Note the scatter induced ripple on the dipole pattern.

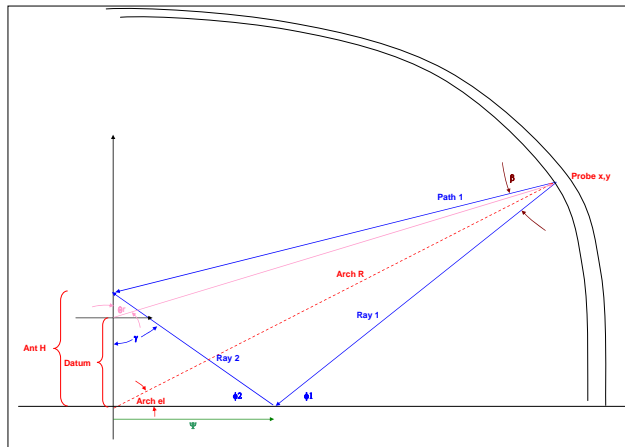


Figure 6 Calculation of Specular Ground Scattering with Elevated Radiating Antenna



Figure 7 Drooping Ground Plane Monopole test with Absorber Placed Close to AUT

As expected from the scattering model, the best

attenuation of the specular scattering occurred with the absorber placed close to the AUT, while the farther out absorber results are almost the same as using no absorber.

Figure 9 shows the mockup on the SSC-SD range, with mockup solar panels deployed. The digging arm is shown in the “down” position. Note that absorber was usually placed on the side of the mockup where the radiating antenna was, to minimize ground scattering, but is not shown in the figure.

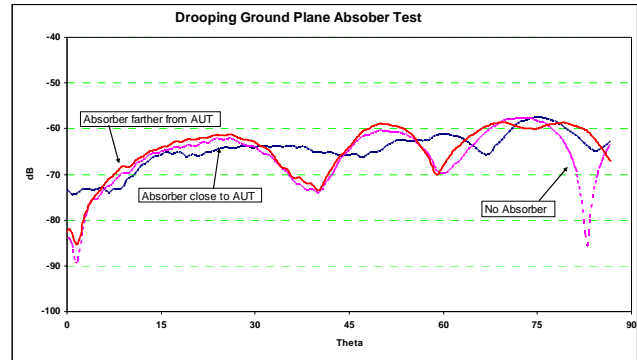


Figure 8 Drooping Ground Plane Monopole Absorber Study



Figure 9 Phoenix Lander Mockup Deployed

4.0 Helix and Monopole Pattern Results

A large number of pattern measurements were taken, but only a few will be summarized here. Figure 10 shows the helix gain co polarization pattern (RHCP) obtained for the surface configuration at the receive frequency of 437.1 MHz, with the arm in the down position. (Measurements were also performed with the arm in high positions and it was found that there is little difference in the patterns. Small variations in the pattern will not on average affect the total data volume throughput).

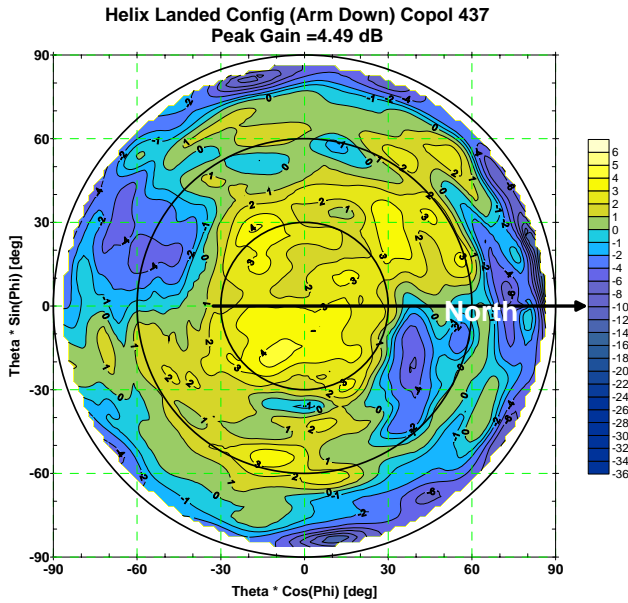


Figure 10 Helix Rx CoPol Gain with Arm Down Position, Landed Configuration

A goal of this study was to evaluate two analysis packages, CST [4] and WIPL-D [5]. *(Note that the authors do not imply endorsement of these products, as there are many such packages on the market these days with similar capabilities).* Figure 11 shows the analysis model of the Phoenix lander. Note that only top surfaces were modeled. Figure 12 shows the CST pattern prediction for comparison to Figure 10. The predicted pattern has been normalized to the measured data peak for easier comparison. These predictions do not include ground scattering effects, and although absorber was used to minimize ground scatter when measuring the patterns in figure 10, some ground scatter is still present. Nevertheless the predictions compare well with the measurements. The predictions from WIPL-D also agree well, and will yield good data volume predictions.

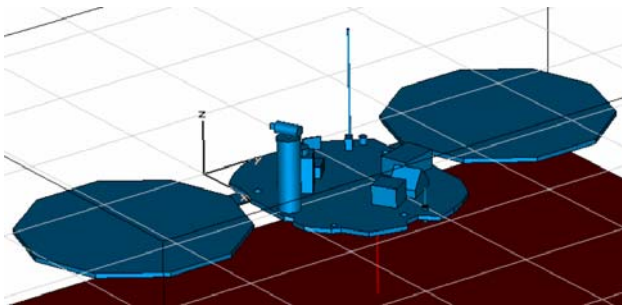


Figure 11 CST Phoenix Model with Ground Effect

Figure 13 shows the north-west oriented pattern of the monopole for receive. (Note Copol = RHCP). The pattern was taken using absorber to minimize ground scattering. Figure 14 shows the same pattern measured without

using absorber. The annular structure seen in Figure 13 is emphasized in 14, due to the increased ground scattering.

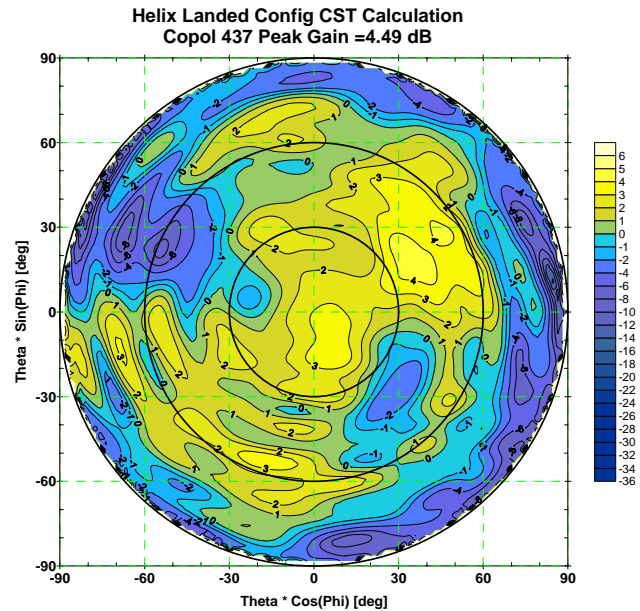


Figure 12 Helix Rx CoPol Prediction using CST (Normalized to measured data, no ground effect included)

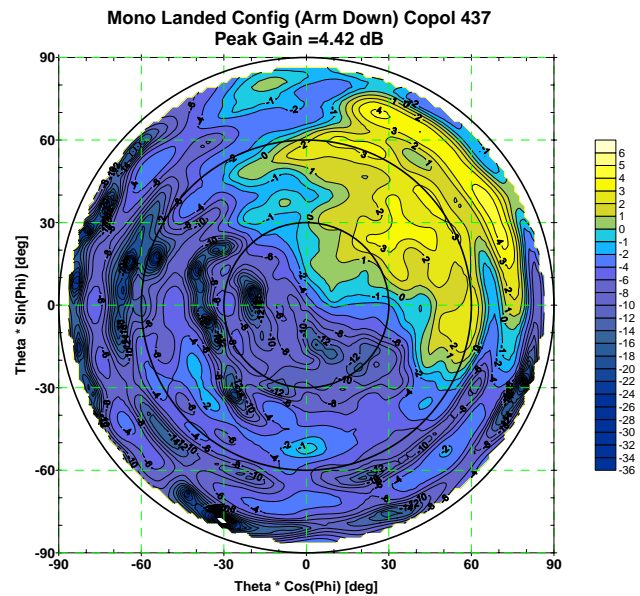


Figure 13 Monopole Rx Copol Gain with Arm Down Position, Landed Configuration

It is expected that since the Martian surface is neither flat nor perfectly conductive, that the patterns in situ will be more like those in 10 and 13, rather than the worst case as exemplified in Figure 14. For data volume calculations the patterns in 10 and 13 (and those for transmit, not shown here due to space limitations) are currently being used by Phoenix systems engineers. For analysis software evaluation however we ran predictions for the non-

absorber case, since the SSC-SD surface was easy to model. Figure 15 shows the CST predictions which includes ground scattering. The predictions compare well with the measurements. The WIPL-D predictions (not shown) also agree with measurements.

As a further example of the prediction capabilities, Figures 16 and 17 show a comparison of the xpol (LHCP) for the transmit frequency, between measured and predicted.

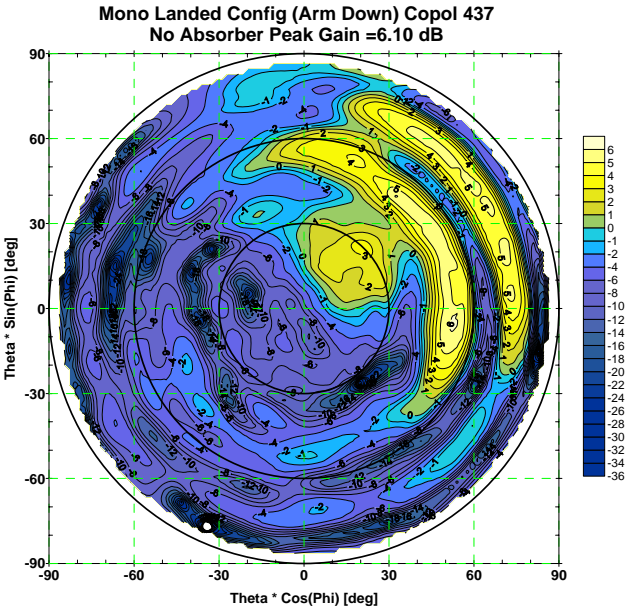


Figure 14 Monopole Rx Copol Gain with Arm Down Position, Landed Configuration, No Absorber

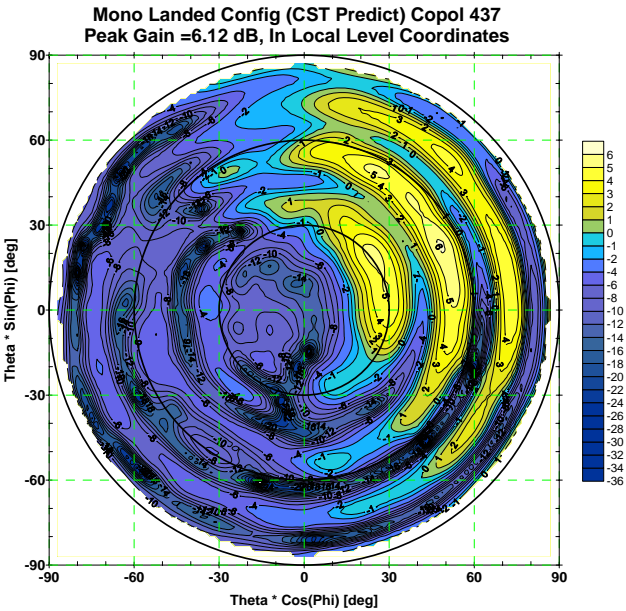


Figure 15 Monopole Rx Copol Gain CST Prediction, Ground Scattering Included

The xpol measured patterns (at both Tx and Rx frequencies) tended to be more symmetric about the north axis (+ve theta*cos(phi) axis), compared to the Copol. The analysis from both CST and WIPL-D show the same symmetry in the pattern structure, as well as the annular structure due to the ground scattering.

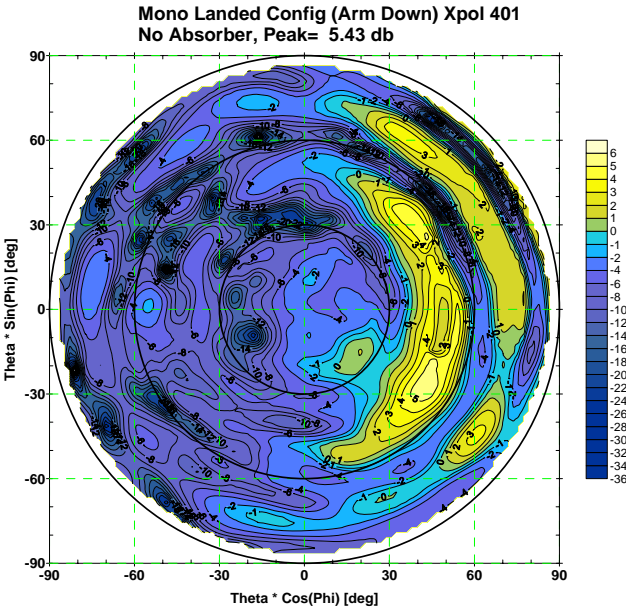


Figure 16 Monopole Tx Xpol Gain measured, No Absorber

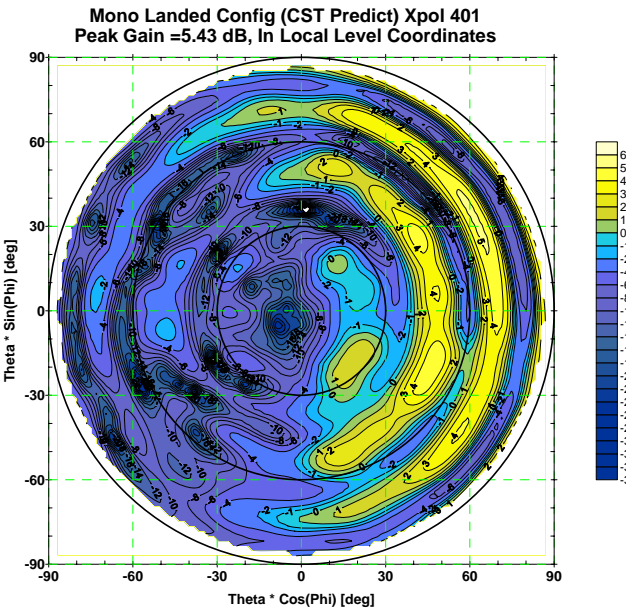


Figure 17 Monopole Tx Xpol Gain , CST Predict with Ground Scattering

Obviously the predicted results will greatly dependent on the physical modeling of the deck and deck objects, as well as the antenna. At UHF frequencies the deviation in the predicted pattern from measured would not be

expected to greatly effected by the differences between the mockup instruments and deck objects, and the analysis model. However many of the objects are rather complicated and in the interests of limiting cost due to excessive modeling the analysis models might be considered crude. Nevertheless the predictions (with its inherent modeling errors) match the measured data (with its inherent measurement errors) well enough to have great confidence that on average we have a good model for Phoenix to orbiter link calculations.

During the mockup tests, the return losses (S11) of the antennas were measured, and comparison with CST predictions, showed good agreement. For example, the measured and predicted S11's for the monopole were found to be as shown in table 1.

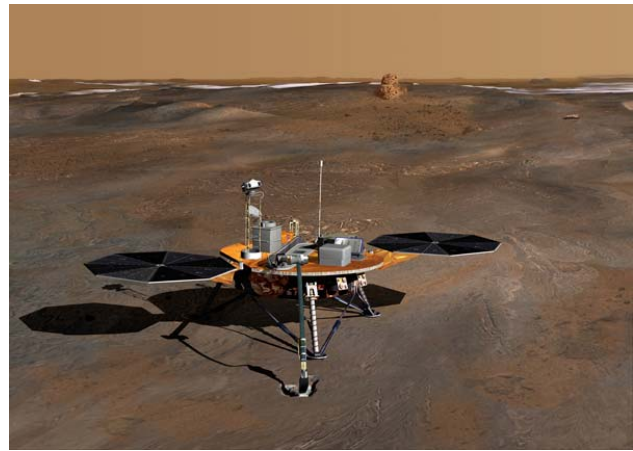
With the verification that monopole pattern was as expected, and return loss prediction capability, we were able to specify an optimum position and height for the monopole to get the pattern required (covering the north-west) and the best possible match.

	S11 measured	S11 Predict
Transmit (401.58)	-11.18 dB	-11.71 dB
Receive (437.1)	-7.69 dB	-6.42 dB

Table 1: Monopole return loss, measured vs. predict

5.0 Summary

The Phoenix lander mockup antenna pattern measurement campaign provided valuable information on the performance of the UHF relay antennas which are to be mounted on the Phoenix lander deck, and allowed empirical verification of the expected pattern of the redundant (monopole) antenna, as well as the helix. The measured data was used to make real time engineering decisions at the system level, and also permitted the validation of two antenna analysis packages, which are being used not only for the Phoenix mission, but also for the next Mars rover mission, MSL. Measured data from this campaign, and analysis results from the prediction packages will also be used to construct data volume prediction tools for use by the operations teams on Phoenix and MSL during the upcoming surface missions.



6.0 REFERENCES

- [1] <http://phoenix.lpl.arizona.edu/>
- [2] Lewicki, C.A., Krajewski, J.A., Ilott, P.A., Dates, J.A., "Phoenix Mars Scout UHF Relay-Only Operations", June 2006, AIAA Space Ops 2006 conference, AIAA-2006-5980 (www.spaceops2006.org).
- [3] Barbieri, A. J., et al., "Development and Flight Performance of CCSDS Proximity-1 on Odyssey and the Mars Exploration Rovers," presented at 2005 IEEE Aerospace Conference, 2005.
- [4] <http://www.sonnetusa.com/products/cst/>
- [5] <http://www.wipl-d.com/index.php>

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